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REPORT R-1656

UNITED STATES ARMY MUNITIONS COMMAND



FRANKFORD ARSENAL

PROPELLANT ACTUATED DEVICE FOR PERCUTANEOUS INOCULATION

by

CHARLES J. LITZ, Jr.

OMS Code 5110.22.011 DA Project 5802-06-001

October 1962

PHILADELPHIA 37, PA.

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PROPELLANT ACTUATED DEVICE FOR PERCUTANEOUS INOCULATION

OMS Code 5110.22.011

DA Project 5802-06-001

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= Uefober 1983

ABSTRACT"

A study was made to determine the feasibility of using the energy of propellant to perform a percutaneous inoculation (administer medication through the skin without an incision). A PAD percutaneous unit was designed, fabricated, and tested in the laboratory. This unit was 3-3/8 in. long by 7/8 in. diameter. It was powered by a modified T14E2 electric ignition element, and used a 0.0031 inch diameter sapphire nozzle. Twenty fixings were made in the laboratory, demonstrating the feasibility of this PAD percutaneous inoculator.

It is recommended that continued studies and testing be performed to perfect and make available an automatic PAD percutaneous inoculation unit for field use.

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FOREWORD

The research work described in this report was performed by the Frankford Arsenal, U.S. Army Munitions Command, Philadelphia, Penna., and was sponsored by the U.S. Army Research Office-Durham, Durham, N. C. The work was accomplished under Army research project order AROD N-6-62, dated 15 January 1962. Br. Sherwood Githens, Jr., Deputy Chief Scientist of the Army Research Office was the project office.

The research program was conducted from January 1962 to July 1962, and was carried out by the Pitman-Dunn Laboratories, Research and Development Group, Frankford Arsenal, under the direction of Mr. Charles J. Litz, Jr. project engineer and chief investigator.

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INTRODUCTION

The administration of medication through the skin (both the epidermis and dermis) into the subcutaneous tissue, without an incision, is known as percutaneous inscription and has been used by medical personnel for some time. In such inoculations, the medication is forced through a small nozzle (placed next to the skin or epidermis) which directs the liquid medication into a fine jet, enabling skin penetration. Recently, the Medical Equipment Development Laboratory (MEDL), Fort Totten, New York, has developed and satisfactorily remonstrated, and now uses a hand-hald, hydraulically leaded, electrically powered, nanually operated injection gun to inoculate groups of people. (1) A medication injection device such as this, but which would function automatically and effectively administer medication percutaneously, would have definite advantages in both field service and space travel.

Frankford Arsenal personnel conceived the idea of employing conventional solid propellant as a primary source of energy for such a device. Based on this concept, a patent disclosure was issued and a technical proposal was drafted and forwarded to the U.S. Army Research Office-Durham (AROD) for consideration. Subsequently, AROD authorized Frankford Arsenal to study such a device by astablishing Research Project Note 52, "PAD for Parcutaneous Inoculation."

At the request of ARCD, Frankford Arsenal parsonnel from the Propellant Actuated Devices Division visited the Walter Reed Army Institute of Research, Washington, D. C., and discussed the project with medical personnel. At that time it was pointed out by the medical personnel that a PAD persutaneous injection unit which could be worn strapped to the body of the coldier in the field and which would sense the presence of nerve gas and automatically inject atropine into the soldier under the narve gas attack, would have definite advantages and could gain wide use, if perfected.

INITIAL STUDY

At the enset of the project and in the interest of economy (funds and time), it was decided to use the sapphire negate of the MEDL injection gum. Such a negate was obtained and became a part of the PAD pertutances unit (Figure 1). In addition to the negate,

^{*}See REFERENCES.

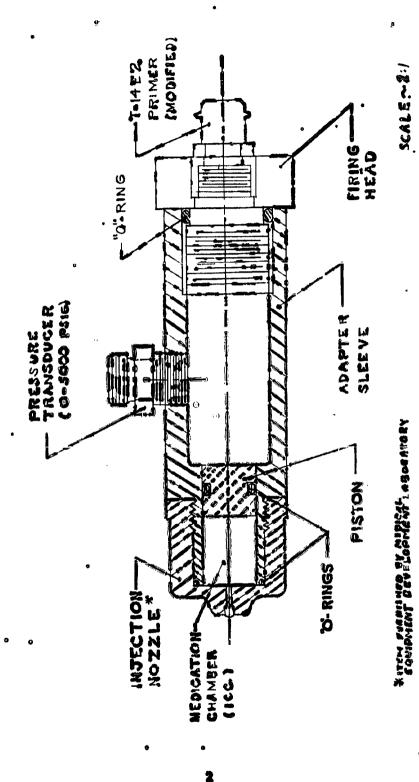


Figure 1. Assembly drawing, PAD Percutaneous Medication Injector

specific sperational parameters of the hypodermic jet injection apparatus were also obtained from MEDL. The significant data obtained are listed in Appendix A.

Using the spring force and the area of the plunger piston, the pressure developed within the MEDL unit was computed. The initial pressure is 4100 psi; the final pressure, after 0.557 inch stroke is 455 psi. It was assumed that if the PAB unit developed the pressure profile of the MEDL unit, the required free stream velocity necessary for percutaneous inoculation would be attained.

Based on the above, pressure and volume relationships were calculated for properliant for the PAD percutaneous unit, using the perfect gas law and an isomtropic analysis. Details of this apply yeis are presented in Appendix 8.

DESIGN OF COMPONENTS

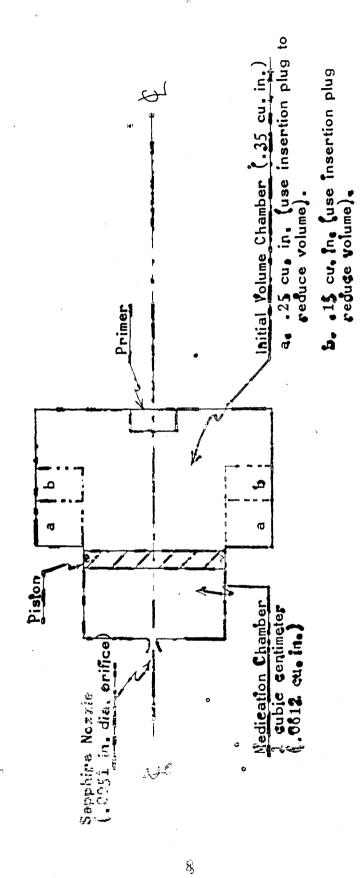
After the propellant analysis (Appendix B) was completed, a laboratory test model of the PAD percutaneous unit was designed with an initial propellant chamber of 0.35 in.3. As fabricated, the PAD unit (Figures 2, 3, and 4) contained a moveable piston and a 1 cc (0.661 in.3) liquid medication chamber.

The unit was designed so the initial volume could be varied by inserting ring type slugs. To assure protection of the nozzle from a high peak pressure, it was decided to test fire the unit first with the largest initial volume. For a given propellant charge, the larger volume would result in a smaller pressure.

From the Stress analysis performed (Appendix C), it was reen that the PAD test unit was over-designed. Thus, the need for designing a smaller, more compact, PAD percutaneous unit for future use Was apparent.

TESTING

For the purpose of taboratory testing, a standard ignition element, the Ti4E2, was modified and used. Figure 5 is a cross-section view of the modified Ti4E2. By means of this modification, energy of the standard Ti4E2 ignition element (which has a 1-1/2 grain lead styphnate pallet) was supplemented with three grains of 220 ball propellant leaded in a caliber .22 rim fire carriage case.



We to scale)

Tighte 2. Cuncept drawing, Laboratory Test this with Warsabis Laternar Falume

Best Available Copy



Pagure 3. PAD Percutaneous Medication Injector (Test Model)

36.231.S2788/ORD.62

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Ç

Tossie "G" Ring Plston "O" King

6. Body f. "O" Zing G. Firing Head H. Modiffed TIRE Element

Figure 4. 2AD Percentanceus Medication Injector (Exploded Vlew)

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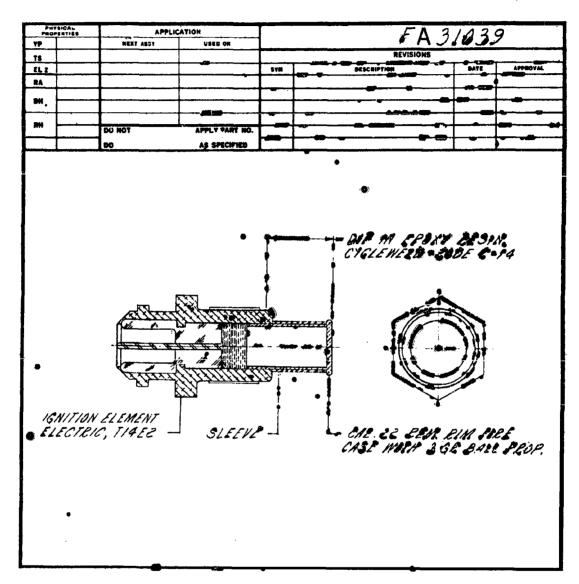


Figure 5. Assembly drawling, Modified \$14E2 Electric Ignition Element

To accommodate this, a small aluminum sleeve, 1/8 inch shorter than the case, was slipped over the case mouth. This assembly was then dipped into epoxy resin for sealing. The chemical composition of the propellant used is presented in Appendix D.

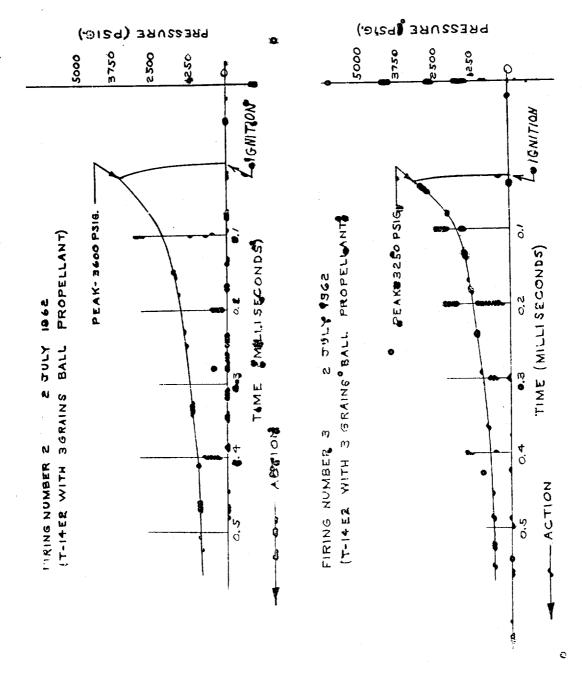
Tests were conducted using a hand-operated impulse generator (output of at least two amperes) to fire the ignition elements. Pressure-time curves were obtained using a Visicorder and a Dynisco (0 to 5000 psig) miniature pressure transducer.

Twenty firings were conducted. After the fifth firing, since the peak pressure recorded was less that the 4100 cs. the internal initial volume was decreased from 0.25 cm. to 0.30 cm. by inserting a hollow ring into the propellant chamber. Calculations for the reduction of the pressure chamber are presented in Appendix E. Figures 6 and 7 are typical performance, curves? Table I lists the test data obtained.

In general, the results of the sests were adjustators. All the simulated inoculant was concern through the nazzle. (Colored water was used to simulate the instructor fiving the Adjunct was disassembled after each test and inspected. These was no evidence of damage to either the sapphire aszzle of the tube body, and there was no visible trace of propellant residue in the medication Chamber.

With one exception (where the except was alonged), there was no propellant blow-by, indicating that the engine on the piston had satisfactorily isolated the propellent gases from the madication. The nozzle clogging was due to a defective dering which permitted some foreign material to plug the nozzle. The material was removed, a new 0-ring inserted, and the unit continued to function exists factorily.

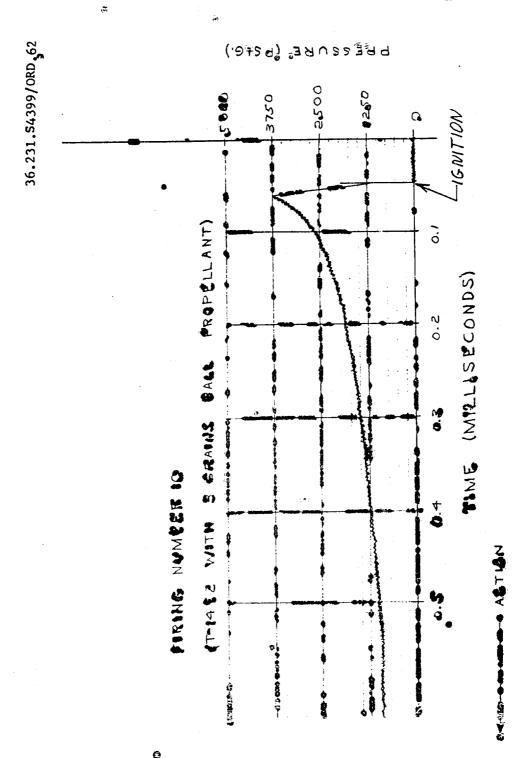
High speed movies (2880 frames (2000) in color, were made of rounds 15 through 20. On rounds 15 through 19, the PAD onit was fired into flesh-simulating material placed next to the nozzle. This material was a gelatin substance (Appendicately 1/2 to 1/2 thick) normally used for small arms studies. The colored (Acceptance penetrated the gelatin material with a fine, needle (386 stream. A container of water placed behind the gelatin material was used to receive the excess ejected fluid. Figure 8 is a color photograph of the test and shows penetration of the test and the tes



7, 3

Figure 6. Aypical Performance Curves, Rounds Ncs. 2 and 3

Ç



E

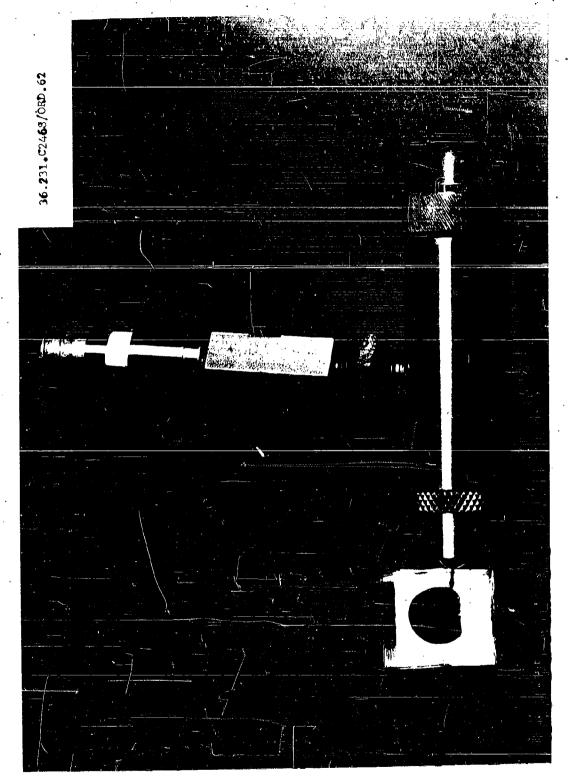
Figure 7. Actua Performance Curve, Round No. 10

TABLE I. Summary of Firing Data

| | | Peak | |
|-----------------------|-------------|------------------|---------------|
| Round | P | ressure | |
| No. | _ | (psig) | <u>Mot:ea</u> |
| 1 | Not | fecorded | 1 |
| 2 | | 3 60 0 | 2,3 |
| 1 2 3 4 5 | | 3250 | |
| 46 | | 2900 | |
| 5 | | 3400 | 4 |
| 6 | | 3200 | |
| 7 | | 1750 | 5 6 |
| 8 | | 3250 | 6 |
| 6 7 8 9 | | 3750 | |
| 10 | • | \$800 | |
| 11 | | 3\$ 70 | |
| 12 | | 3958 | |
| 13 | | 3200 | |
| 14 | • | 280 | |
| 23 | Jok | facet (e 🏚 | 7 |
| 16 | No t | recorded | |
| 17 | Not | recorded | |
| 18 | No t | rec erded | |
| 19 | · Not | reconded | 8 |
| 20 | | *ees de | 9 |

Notes:

- 1 First tatal string with a refused thatge, possisting of an M52A3 primer, which is standard for the 20 mm round. The piston did not complete stroke the to the fifteen pressure,
- 2 Modified T14E2 ignition element used for all subsequent firings,
- 3 An 0.047-inch cardboard, backed up with several thicknesses of paper, was placed next the the wazzle to measure the penetration of the simulated measure to make a simulated measure to measure to penetration.
- 4 Initial volume of propellars chamber degreed from 0.35 to 0.30 in.3.
- 5 Defective primer.
- 6 Gelatin fiesh simulator meed for rounds & through 19.
- 7 Pressure not remarked instead, high speed (288) frames/second) . metter picture coverage was used for all subsequent fests.
- 8 Sapphire nozale clogged; piston did not complete stroke.
- S' Simulated medication fluid ejected into free ait.



CONCLUSIONS

The feasibility of the PAD percutaneous medication inoculation unit has been demonstrated. Thus, the basic concept as presented in the Frankford Arsenaf proposal (AROD N=61) has been removed from the realm of abstractness.

RECOMMENDATIONS

It is recommended that studies with the PAD percutaneous unit be continued. Particular emphasis should be placed on improving the performance and cafety factors of the laboratory test model to make it suitable for tests on live subjects. Testing with live animals would naturally precede personnel evaluation studies.

FUTURE WORK

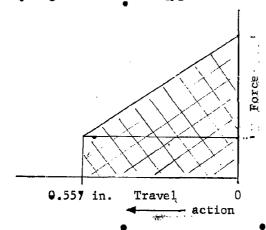
A salt such as the PAD percutaneous medication injection unit, with its automatic feature, could be used in space travel or under CBR (chemical, biological, and radiological) conditions. For example:

- In space travel, the need for an automatic, remotely actuated, medication—administering device is evident. Such a device would replace the presently self—administered unit used in space (see Appendix F). Medications administered to personnel in space are designed to help offset injuries and/or uncomfortable sensations in flight, and to counteract physical and psychological disabilities resulting from gravitational differences or atmospheric variations.
- 2. Nerve gas is odorless, and the Army has developed a nerve gas detector (Appendix 6) which senses the presence of such gas, sounds an alarm, and causes lights to flash. A spring-loaded hypodermic needle attached to a vial containing the liquid medication (atropide) to offset the effects of nerve gas, is currently available for use in the field. The PAD percutaneous medication-injection unit, if incorporated with such a detector (as discussed in Appendix 6) could be used to administer atropine automatically under nerve gas attack. This automatic injection can be accomplished by means of a radio transmitter, energized by the gas sensor, and a miniature radio receiver, attached to the PAD unit. On receiving the transmitted lightly the radio receiver fires the propellant charge, causing the PAD percutaneous unit to inject the atropine.

APPENDIX A

FORCE-STROKE DATA FOR "MEDL" UNIT

A spring is used as the source of energy to force a 3/8 inch diameter piston plunger rod ferward and, subsequently, to force the medication through the 0.0051 inch diameter sapphire nozzle. The spring has the following characteristics.



Initial Force: 450 1b (Pressure Developed: 4100 psi)

Final Force: 50 1b (Pressure Developed: 455 psi)

Also, in normal operation (using the spring) the unit ejects the 1.cc of medication into free space in approximately 0.45 second.

APPENDIX B

FEASIBILITY STUDY, PERFECT GAS LAW AND ISENTROPIC ANALYSIS

This analysis is based on an isentropic process which is a reversible adiabatic process during which no heat is transferred to or from the working substance. In the isentropic process, the working substance loses or gains energy as work, but not as transferred heat. In the actual operations of the PAD unit, some heat will be lost during the thrust cycle. It is also assumed that no piston movement will be obtained from the primer during gas evolution. The inertia in the medication fluid, daused by resistance generated on its passage through the orifice, will cause the inlial column to all in a locked-shut manner during the time of gas evolution.

From thermodynamic characteristics of all perfect gases, the equation of state for any perfect gas is

$$PV = nRT \tag{1}$$

For real gases, Equation (1) is only approximately correct and is normally corrected for the behavior of actual gases which are not fractionless in their behavior and are composed of particles of finite volume. VanderWaals, Berthelot, or Virial coefficient equation techniques are normally used to do this.*

For this analysis, the approximate approach was used. Equation (1) may be rewritten

$$PV = g(nRTv)$$
 (2)

where

P = instantaneous pressure (psi)

V = internal initial volume of device (in.³)

g = propellant charge weight (1b)

(nRTv) = propellant impetus, I (in.-lb/1b)

m = number of moles of propellent gas

R = Sniversal gas constant

Tv = instantaneous gas temperature (*K) (volume constant)

^{*}See pages 2 to 13, Reference 2.

Compute the Internal Initial Volume, V, of the PAD Percutaneous Unit.

The MEDL unit develops a peak pressure, P, of 4100 psi.

The modified T14E2 ignition element contains 1 gram lead styphnate and 3 grains ball propellant.

The impetus, I, of this propellant combination is estimated to be in the order of 2.5 x 10^6 in.-1b/lb.

Using Equation (2) and the above factors,

(4100 lb/in 2) (V) =
$$\left(\frac{4 \text{ gr}}{15 \text{ gr/gm}}\right) \left(\frac{1}{454 \text{ gr/lb}}\right)$$
 2.50 x 10⁶ 2n.-1b/lb
V = $\frac{\left(\frac{4}{15}\right) \left(\frac{1}{454}\right) \left(2.5 \times 10^6\right)}{4100}$

$$V = 2.358 in.5$$

The initial pressure and volume for a working model can be expected to be semewhat less than that calculated. This is brought about since there will be some heat losses from the system. With the design of the PAD test anit (Figure 2), the pressure can be increased by decreasing the chamber volume.

APPENDIX C

DESIGN DATA AND STRESS ANALYSIS

The adapter sleeve is a stainless steel, cylindrical tube with 5/8-18NF-2A external and 5/8-18NF-2B internal threads on either end. A pressure pick-off hole with 1/8-27NPT threads for mounting the pressure transducer is located on one side of the unit (see Figure 1). The expected peak pressure for the test unit, which was constructed for repeated firings, was 4100 psi.

For this analysis, the distortion-energy theory of failure (von Mises-Hencky), which is the accepted criteria for the design of duce tile materials under combined loads, such as a pressure vesse), was used.*

For a biaxial stress condition, the fellowing equation applies?

$$\frac{P}{Y} = \frac{W^2 - 1}{\sqrt{(3W^4 + 1)}}$$

where

P = maximum pressure (psi)

Y = yield strength of material (psi)

 $W = \text{wall ratio}, \frac{OD}{TD}$

The wall ratio for the PAD unit is

•
$$W = \frac{OD}{ID} = \frac{.85}{.60} = 1.416$$

The maximum pressure for the adapter sheeve is

$$\frac{P}{Y} = \frac{(1.446)^2 - 1}{\sqrt{[3 (1.416)^4 + 1]}}$$

$$= \frac{1}{3.61}$$

$$P = \frac{160.009}{3.61}$$

$$= 44.300 \text{ psi}$$

where Y = 160,000 psi, yield stress for stainless steel.

^{*}See page 29, Reference 3.

Margin of Safety:

$$MS = \frac{44.300}{4100} - 1 = 9.8$$

Length of Thread Engagement

The length of thread engagement is calculated from the following equation.*

$$L = \frac{3PR^2}{S_s d} \tag{C2}$$

where

L = length of thread engagement (in.)

P = maximum internal pressure (psi)

Ss = shear strength (psi)

R = major radius of female (max) (in.)

d = minor drameter of male (min) (in.)

Equation (C2) includes a 1.5 safety factor to allow for tolerance and the distribution of stress within the engagement.

Nozzle and Firing Head - 5/8-18NF threads

For this analysis the length of thread engagement for the nozzle was considered the weakest member of the two 5/8-18NF threaded ends. The shear stress for the nozzle material is 50,000 psi, whereas the shear stress for the adapter sleeve material is 95,000 psi.

$$L = \frac{3(4100)(0.3125)^2}{(50,000)(0.5568)}$$

= 0.0435 in.

This design is more than adequate. The actual length of thread engagement is 0.250 inch.

Pressure Tapped Hele . 1/8-23NPT threads

$$\frac{3}{1} = \frac{3(4100)(0.2025)^2}{(95,000)(0.334)}$$

= 0.0157 in.

This design is more than adequate. The actual length of thread engagement is 0.12 luch.

*See page 29 Reference 3.

APPENDIX D

CHEMICAL COMPONENTS OF PROPELLANT

820 Ball Propellant

| Nitroglycerin | 9 2 13%, | |
|-------------------------------|----------|---------|
| Diphenylamine | 0.97% | |
| Deterrent | 2.50% | |
| Graphite | 0.21% | |
| Total volatiles | 1.35% | |
| Moisture | 0.89% | |
| Ash | 0.04% | |
| Nitrocellulose* | 84.89% | |
| Witiocelidiose | | 100.00% |
| *Nitrogen in nitrocellulose | 13.15% | 200,000 |
| | | |
| M52A3 Primer | | |
| Normal lead styphnate | 40.0% | |
| Barium nitrate | 44.2% | |
| Acetylene black | 0.8% | |
| Calcium silicide | 13.0% | |
| T.N.R. (tri-nitro-resorcinol) | 1.0% | |
| Gum arabic | 1.0% | |
| 1711111 CLICALILL | | |

100.8%

APPENDIX E

CALCULATIONS FOR REDUCTION OF PRESSURE CHAMBER

Summarized herein are calculations to determine a new initial volume. This was done to increase the peak chamber pressure of the PAD unit. The average pressure recorded for three firings (rounds 2, 3, and 4) was 3600 psi. The MEDL unit develops a peak pressure of 4100 psi (Appendix A).

For a reversible adiabatic (seatsopie) protess

 $PV^{K} = Constant during the change$

where

P = Instantaneous pressure (psi)

V = internal volume of device (in.2)

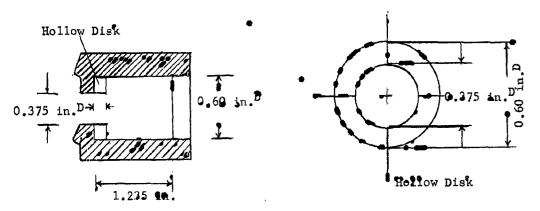
K = ratio, Cp/Cv; use 1.3

(3600 psi) (0.35 in.3)^{1.3} = (4100 psi) (V in.3)^{1.3}

$$\frac{3600}{4100} = \frac{V}{0.35}$$

$$V = 0.316 \text{ fm.}^3$$

The internal volume of the wait was reduced from 0.35 to 0.30 ln. by inserting a 1/4 inch thick hollow disk into the propellant chamber. The size of the hollow disk used is illustrated below.



The 0.60 in. D is the inside diameter of the internal volume of the propellant chamber. The 0.375 in. D is the outside diameter of the plunger piston.

APPENDIX F

MEDICAL KIT FOR ASTRONAUTS

Drugs are a vital unit in the medical kit of the astronauts.

Medicine at Work, publication of the Pharmaceutical Manufacturers Association, said that astronauts Afan Shepard and Virgil Grissom each took along four vials of drugs with hypodermic needles attached - handy for prompts self-administration.

The publication noted that these drugs are designed to help offset uncomfortable sensations in flight, injuries, and to counteract physical and psychological disabilities resulting from gravitational differences or atmospheric variations.

The Evening Bulletin Philadelphia Twesday, November 27, 1962 Date line: Washington

APPENDIX G

ARMY DEVELOPS DETECTOR TO WARN GIS OF NERVE GAS

The Army has developed an automatic device that can detect deadly nerve gases in time to save the Atves of intended victims. The mechanical-chemical alarm has been ordered into production, the Army said, and should be in the hands of fighting units in a "few years." The device was described as "reasonably foolproof," based on 1,000 hours of testing in various climates.

An Army spokesman said there was no nerve gas known to medicing which settld net be detected by the automatic alarm, a 28-1b device somewhat resembling a tape recorder.

* * * * *

The Army pointed out that a soldier would receive a fatal dose of nerve gas if he had to depend on his own senses to detect its presence. Nerve gases are odorless, colorless, and do not produce a physical sensation until the appearance of adverse symptoms. Then it is too late to put on masks and apply treatment.

Electric Eyes Used

The detector contains a tape on which a spot appears if a nerve agent is present. An electric eye sees the purplish spot and causes lights to flash and horns to sound. The Army said the system would not react to any agent except nerve gas.

The alarm can be carried by a soldier, or it can be mounted on an armored vehicle or a place at a distance from a command post and observed through field glasses.

It was developed by the Army chemical research and development laboratories and Air Craft Armaments, Inc., Cockeysville, Md.

The Evening Bulletin Philadelphia Tuesday, July 10, 1962 Date line: Washington

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